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ANALOG DIGITAL CORRELATOR

ABSTRACT

This article discusses the principles of operation and the construction of an analog digital correlator, in which the functions to be correlated are supplied in the form of curves, and the result appears in the form of numbers. Pulse generators using photomultipliers and cathode ray tubes displaying television rasters are employed in the correlator. In the generator the electron beam scans the screen of the cathode ray tube yielding for each ordinate a number of pulses proportional to the position of the mask of the given curve. Thus, the ordinate representations are multiplied in the pulse-number multiplying block. The result is produced either in tabular form or as the curve of the correlation function.

1. The Idea of Operation

The described apparatus comprises a (specialistic) mathematical machine, which is designed for the realization of correlation analysis.

This machine computes one of the most important statistical characteristics--the correlation function[2] by use of the approximate formula:

$$R_K = \frac{1}{N} \sum_{i=1}^{N} x_i \cdot y_{i+k}$$

The functions to be correlated, $x(t)$ and $y(t)$ are divided into 2N intervals so that R_K may be computed for K traversing the range 0 to N. The functions $x(t)$ and $y(t)$ are introduced into the correlator as templates on the cathode ray tube faces at which the photomultipliers look through their respective optics (Fig. 1).

The electron beam forms a television-type raster on the face of the cathode ray tube. During a scan of one of the electron beams at the instant a_i (Fig. 2) gate W_1 opens and passes pulses from pulse generator G_1 into the pulse number multiplier M until the spot appears from behind the template and is noticed at time b_i by the photo multiplier which closes W_1.

By this method the value x_i, to a given accuracy, is

[2] Superscripts refer to references.

stored as a number of pulses proportional to x_i in a counter in the multiplier.

At time C_i (for a given K) the spot on the other cathode ray tube starts its scan to the ordinate y_{i+k} and proportionately, the number of pulses. These are passed to the multiplier, at whose output we read $x_i \cdot y_{i+k}$ in the form of a number of pulses summed by counter P_3. When both spots, for a given K, traverse N ordinates of the functions to be correlated, counter P_3 registers the number of pulses proportional to the K^{th} ordinate of the correlation function being computed. The apparatus indexes K and records the value for each point in the correlation function.

After completing the counting cycle, i.e., when K = N we receive the sought correlation function as a table of values defining its ordinates. It is evident from the description that the main parts of the correlator are: the analog-digital converter, the pulse number multiplier, and the control block.

2. Analog-Digital Converters

The analog-digital conversion is based on a stepped approximation to the function divided into 2N equal intervals.

The subdivision is roughly N = 100. The number of pulses corresponding to a maximum ordinate is 2^7. This makes it theoretically possible to measure ordinates to better than 1 percent (of full scale). There are two converters working alternately in the correlator. The vertical deflection is obtained from a triangular wave fed to the cathode ray tubes in two opposing phases.

Because of this, during the retrace of one of the converters, the other is performing an active scan without the danger of an error occurring in the alteration of pulse trains (ordinates). The horizontal deflection is obtained from a mutual sweep generator. In one of the converters the control block adds a DC term to the horizontal deflection voltage, thereby realizing K .

3. Pulse-Number Multiplier (I)

The multiplier consists of two seven bit counters P_1 and P_2 (Fig. 3) and seven and gates. A number of pulses D , proportional to x_i, appears at the input to counter P_1. The flip flops of counter P_1 corresponding to succeeding positions D_j of the number D stored in P_1 control gates W_j. If flip flop D_j contains a one, gate W_j is open.

After the gates are set up, a number of pulses C proportional to $y_i + K$ is fed to counter P_2. Thus, after the first flip flop of P_2 we have C/2 pulses, after the second, C/4, etc.

The pulse trains emitted by each of these flip flops are routed through the gates W_j of the multiplier output register. Gates W_j are open to those plates on which the received pulse trains do not overlap. Due to this, the number of pulses the output register receives is:

$$F = \frac{C}{2^1} D_7 + \frac{C}{2^2} D_6 + \dots + \frac{C}{2^7} D_1 = \frac{CD}{2^7}$$

Since the number appearing at the multiplier output is always integral, if C is not an integral multiple of 2^7, the result in the multiplication is in error. To obtain this error within given limits, the authors constructed the machine so that the number of pulses proportional to y_{i+k} is always an integral multiple of 2^4 and equal to 2^4C

$$0 \leq C \leq 2^7 .$$

It follows that the above formula becomes:

$$F = 8CD_7 + 4.CD_6 + 2.CD_5 + CD_4 + \frac{C}{2} D_3 + \frac{C}{4} D_2 + \frac{C}{8} D_1 = \frac{CD}{8}$$

Thus, the maximum absolute error is 17, which in comparison with the maximum result of the computation makes the relative error

$$\mathcal{E} = \frac{17}{2^{14}} . 100 \quad 0.1 \text{ percent}$$

4. Control Block

The block diagram of the correlator is shown in Fig. 4. The basic operating cycle of the correlator is as follows: the x_i ordinate count, the y_{i+k} count, and their multiplication.

The basic cycle is controlled by trigger T_1. Complementation of the trigger is due to multivibrator G_3 at a frequency of

50 cy. The square wave output of T_1 is integrated, and the resulting triangular wave supplies the vertical deflection to the converters. Simultaneously, the wave from T_1 is differentiated and the resulting negative pulses at 25 cy. are counted in counter P_4 and serve to reset counters P_1 and P_2 in the multiplier.

The use of gates W_1 and W_2 in the converter block was described in paragraph 1. Let us say that trigger T_1 defines the alternation of pulse trains from the converter to the multiplier.

When counter P_4 indicates 100 basic cycles, counter P_3 indicates the value of the correlation function. Simultaneously, the 100th pulse overflows counter P_4 and complements Trigger T_2 which closes gates W_3 and W_4 and signals block K. (Block K indexes the variable K).

The same pulse, after a delay in block δt (a one-shot multivibrator) resets counter P_3 readying it for the next value of the correlation function. Besides this, the delayed pulse recomplements T_2. As a result of the T_2 state change, gates W_1 and W_2 open and the horizontal sweep generator is triggered. This initiates the next series of 100 cycles required for the computation of another point on the correlation function.

As implied above, the vertical scan time is 1/50 sec. Thus the natural period is 1/25 sec. (for an x_i count and a y_{i+k} count). Since N = 100 4 seconds are required to compute one point on the correlation function.

The computation of 100 values of the correlation function requires 400 sec. or about 7.5 minutes. For the above times, generators G_1, G_2, G_3 operate at 102.4 kc, 6.4 kc and 50 cy. respectively.

Error-free operation of the correlator does not require great frequency stability of the above generators, but only a constant relation between them. This is obtained by synchronizing all the generators to one, the frequency of which equals the frequency of read out.

References:

1. A.A. Feldbaum - Computational Devices in Automatic Systems, Moskva 1959
2. V.V. Solodovnikov - Statistical Dynamics of Linear Systems of Automatic Control, Moskva 1960

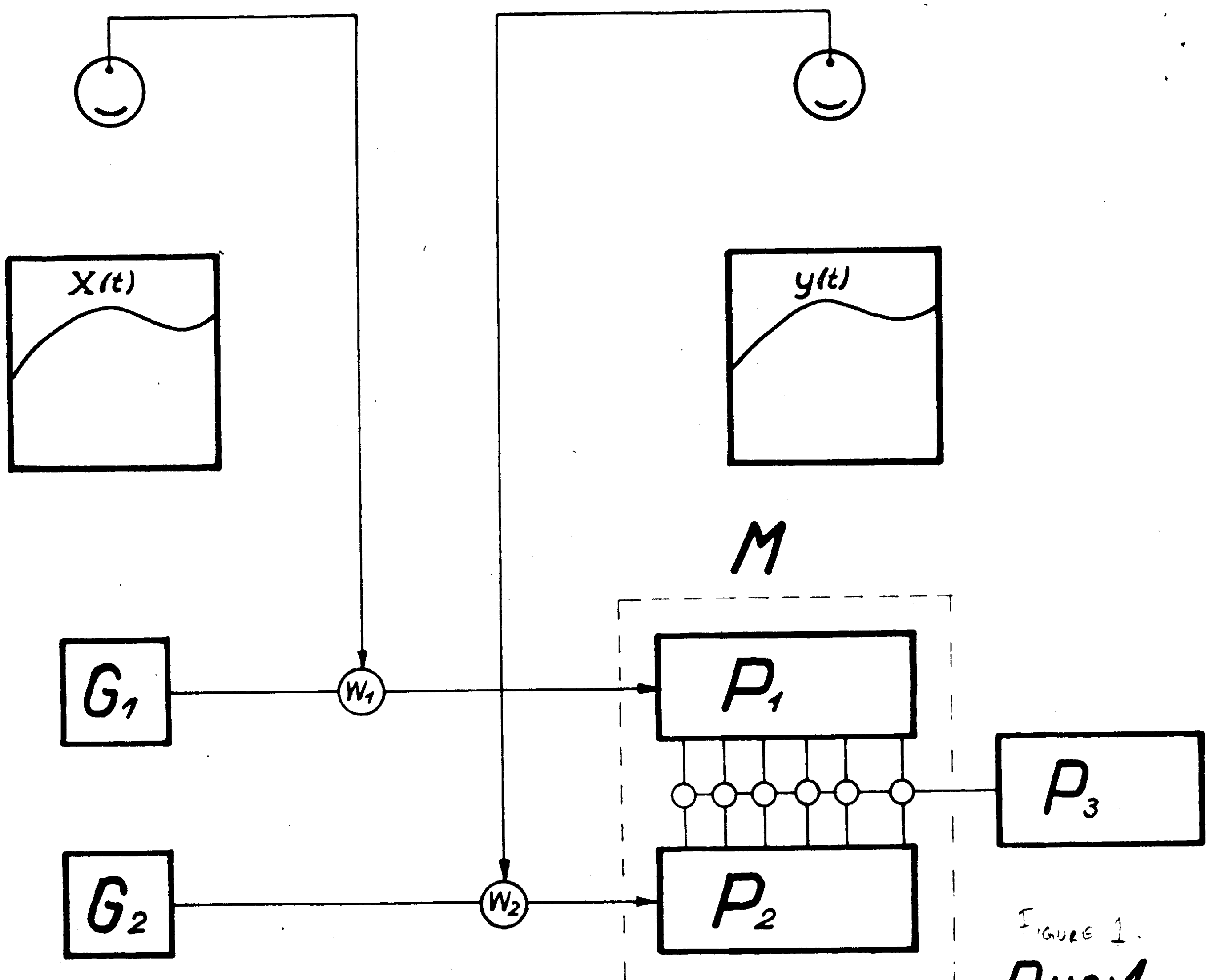


Figure 1.
Рис.: 1.

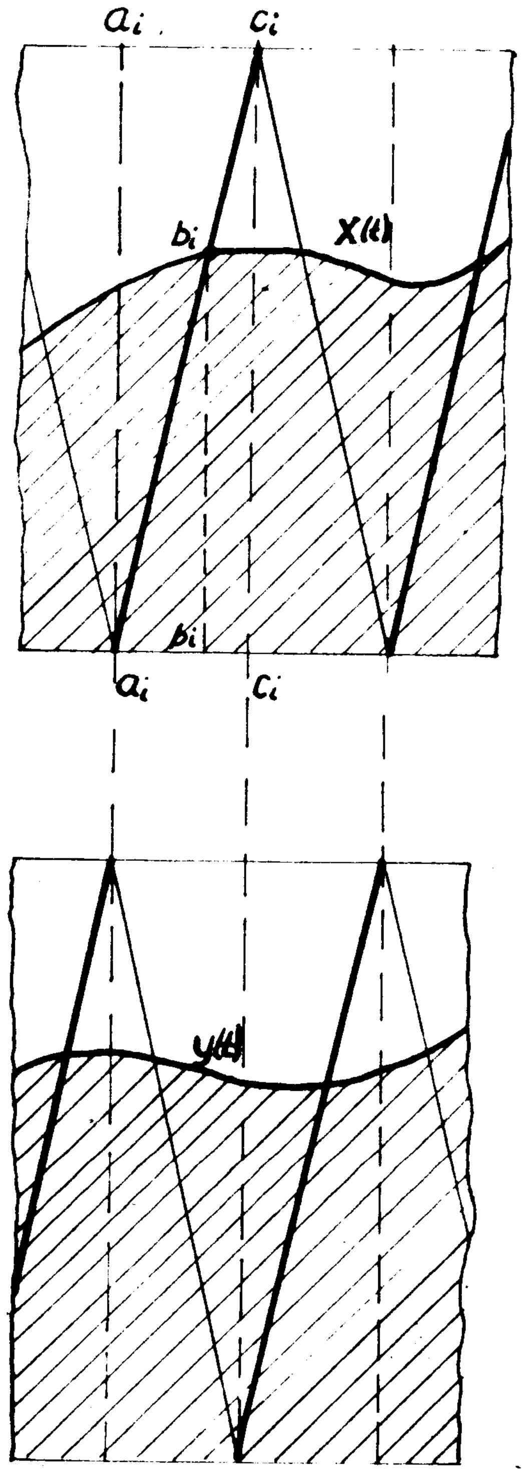
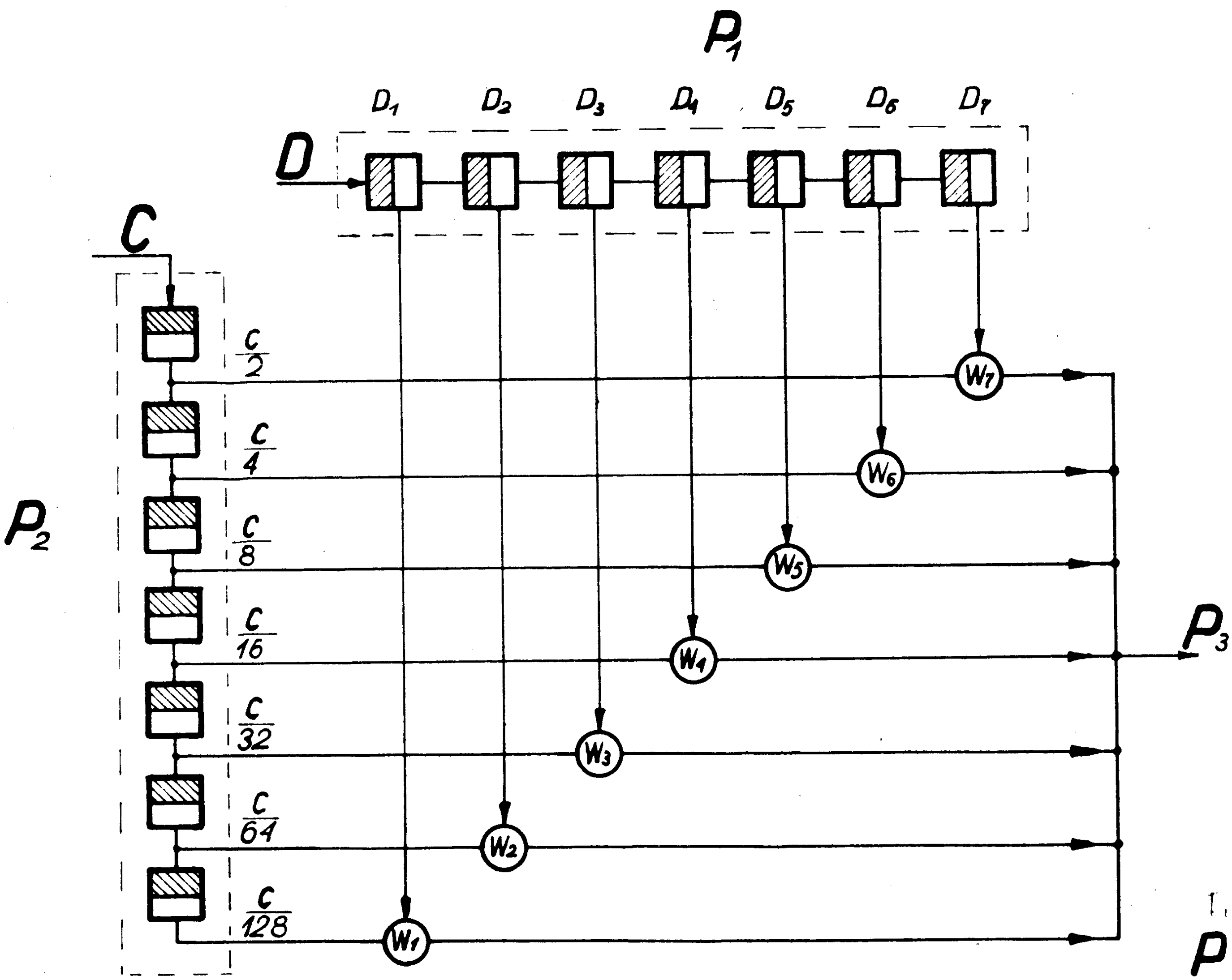


Fig 2.



P_1
D_1 D_2 D_3 D_4 D_5 D_6 D_7
D
C
P_2
$\frac{C}{2}$
$\frac{C}{4}$
$\frac{C}{8}$
$\frac{C}{16}$
$\frac{C}{32}$
$\frac{C}{64}$
$\frac{C}{128}$
W_7 W_6 W_5 W_4 W_3 W_2 W_1
P_3

Fig 3

Рис: 3.

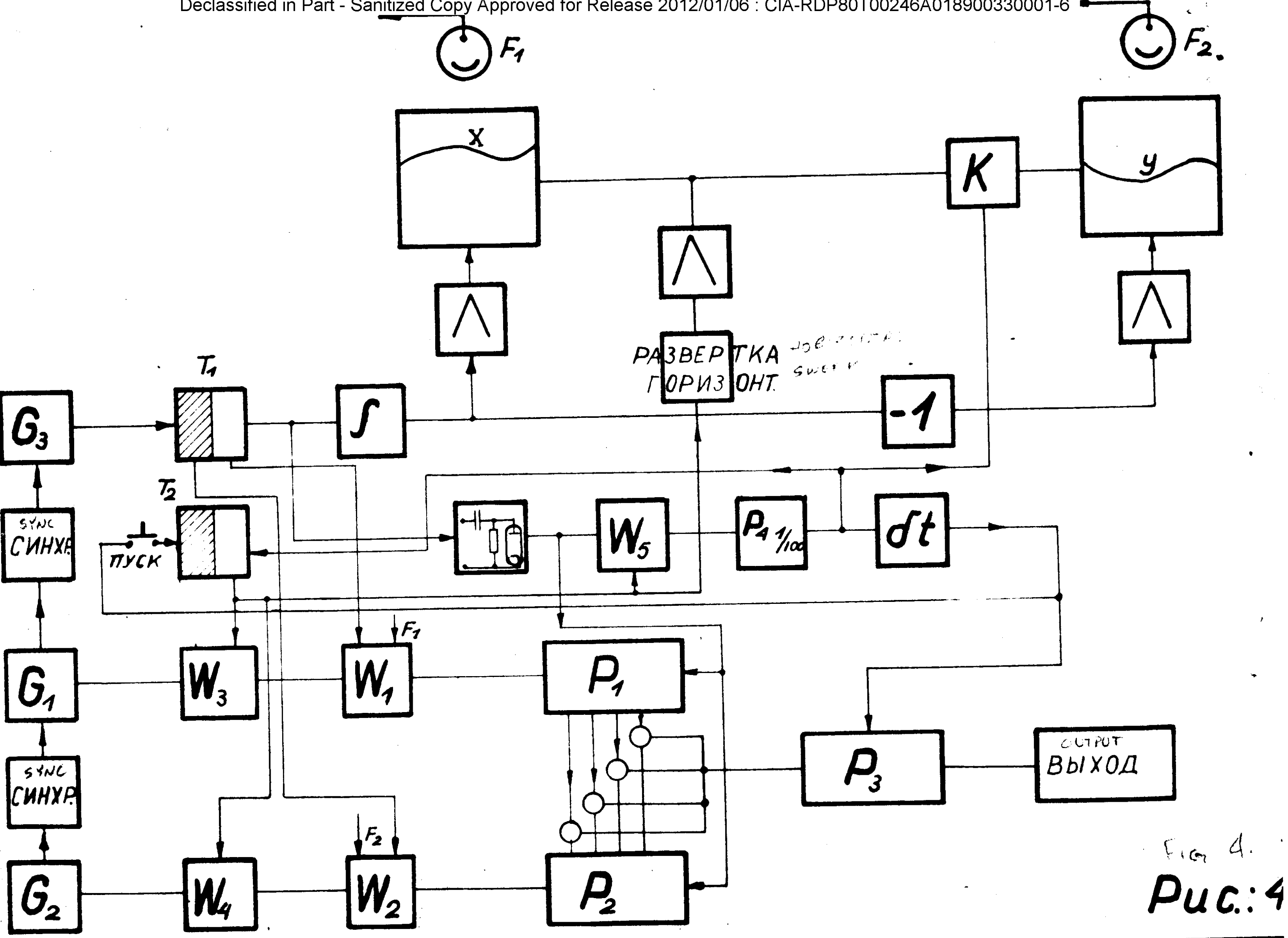

F_1
F_2
x
y
K
РАЗВЕРТКА ГОРИЗОНТ.
T_1
T_2
G_3
SYNC
СИНХР.
ПУСК
W_5
P_4 1/100
δt
-1
G_1
W_3
W_1
P_1
P_3
OUTPUT
ВЫХОД
SYNC
СИНХР.
G_2
W_4
W_2
P_2

Fig. 4.

Рис.: 4